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Temporal Databases: Research and Practice

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Preface

Temporal databases incorporate the concept of time to create high-level abstractions useful in database applications. This has been an active area of research for about twenty years. In the last few years the importance of the temporal database area has been recognized by the international scientific community. This recognition came in part in the form of the ARPA/NSF sponsored International Workshop on Temporal Database Infrastructure in 1993, a VLDB-affiliated temporal workshop in 1995, a special section of the IEEE Transactions on Knowledge and Data Engineering on temporal and real-time databases published in August 1995, and the incorporation of temporal constructs, proposed by the temporal database community, in the soon-to-be standardized SQL3 language.

This book arose out of the Dagstuhl seminar that was organized by us during June 23–27, 1997. This seminar focused on the future directions of this discipline, with respect to both research issues and the means to incorporate temporal databases into mainstream application development. List of topics discussed at this seminar included:

1. Temporal data models: relational, object-oriented, deductive, and hybrid models. Where do the temporal capabilities fit in?
2. Temporal languages: TSQL2 and beyond. Update and retrieval languages for various types of temporal data models.
3. The interrelationships between temporal databases and other disciplines: spatial databases, active databases, deductive databases, real-time databases, information uncertainty, belief revision, etc.
4. Implementation issues in temporal databases. Issues that arise from experience of implementors and users and the agenda for research into these areas and transition to use in practice.
5. Strategic discussions about the future of "temporal databases" as a discipline. Evaluation of the current state of the art and "call for action" to the community.

The Dagstuhl seminar brought together researchers who have dealt with different perspectives on temporal databases: temporal data models, temporal retrieval and update languages, interrelationships between temporal databases and other database technologies (e.g., spatial databases, active databases, real-time databases), and interrelationships between temporal databases and temporal reasoning in artificial intelligence. Some of the invited participants have also been involved in the standardization activities of the temporal community. Having a diverse group that shared a focus on temporal information processing ensured critical evaluation of the activities that have occurred thus far, and enriched the discussions.

As with any Dagstuhl seminar, the participants respresented a selected group of prominent researchers in the subject area. We solicited from the Dagstuhl

seminar invitees submissions for this book and aimed to include high-quality original papers about the state of the art in the temporal database area. The number of submissions exceeded our expectations, and we used a peer-review process to select the high-quality papers for this book.

The book consists of the following parts:

Part 1: Temporal Database Infrastructure: This part consists of five papers that discuss infrastructure topics.

The relationship between object-oriented modeling and temporal databases is one of the emerging issues, because of the inherent data complexity of temporal applications. The paper **An Object-Oriented Framework for Temporal Data Models** by **Goralwalla, Ozsu,** and **Szafron** presents an object-oriented basis for the design and implementation of different temporal data models, to capture alternative temporal models for different applications and to compare and analyze different temporal object models with respect to design dimensions.

Heterogeneous system problems of semantic differences with respect to time-related data do not escape temporal database applications. These differences can materialize in point versus interval semantics, different granularities, and different data types. The paper **An Architecture for Supporting Interoperability among Temporal Databases** by **Bettini, Wang,** and **Jajodia** proposes a multidatabase architecture where an appropriate formalization of the intended semantics is associated with each temporal relation. This allows the construction of a temporal mediator, described in this paper.

While retrieval queries in temporal databases have been thoroughly discussed, the update process deserves some attention. The paper **Extended Update Functionality** by **Etzion, Gal,** and **Segev** provides an enhanced collection of update operation types that are possible in append-only temporal database applications (such as: freeze along an interval, revise an erroneous value over an interval keeping the previous value for historical queries). The paper discusses different possible semantics for simultaneous values (values that are valid during the same valid time), and discusses the concept of *decision time* as a temporal primitive.

The execution of temporal database updates and queries can be optimized, due to the fact that an operation refers to specific time points. The paper **On Transaction Management in Temporal Databases** by **Gal** provides a framework for concurrent processing of retrieval and update operations in temporal databases. The paper presents a series of modifications and tuning facilities for traditional concepts in transaction management, especially the locking mechanism. The paper **Implementation Options for Time-Series Data** by **Elmasri** and **Lee** concentrates on a special topic of temporal databases: time-series management systems. This paper compares and demonstrates different implementation schemes of mapping time-series into relational and object-oriented databases.

Part 2: Temporal Query Languages: This part consists of four papers that deal with query languages and their relationships to modeling and implementation.

Nested relations have been mentioned as a representation scheme for temporal data. The paper **Expressive Power of Temporal Relational Query Languages and Temporal Completeness** by **Tansel** and **Tin** introduces an extension to the relational data model to handle temporal data and queries, based on a nested relational data model. This model captures tuple and attribute time-stamping. The paper discusses requirements for such a model and temporal relational completeness.

One of the efforts in the last few years has been the attempt to incorporate temporal capabilities in the SQL standard. The TSQL2 language is the proposed language that has been devised by a committee consisting of many of the leading researchers in the temporal database community. The paper **Transitioning Temporal Support in TSQL2 to SQL3** by **Snodgrass, Bohlen, Jensen,** and **Steiner** summarizes the proposals before the SQL3 committees to allow the addition of tables with valid-time and transaction-time support and explains how to migrate from a regular relational database into the proposed scheme.

The efforts to incorporate temporal capabilities into SQL have stimulated some discussion with respect to the nature of the desired target language. The paper **Valid Time and Transaction Time Proposals: Language Design Aspects** by **Darwen** suggests language design principles, such as parsimony and conceptual integrity, and argues that current proposals deviate from these design principles. This language debate was discussed at length during the Dagstuhl seminar.

Point-Based Temporal Extensions of SQL and Their Efficient Implementation by **Toman** is the topic of the next paper. This paper proposes another extension to the SQL language by adding a single data type to represent a linearly ordered universe of individual time-instants. In addition it introduces an efficient query evaluation procedure over a compact interval-based encoding of temporal relations.

Part 3: Advanced Applications of Temporal Databases: This part consists of four papers that discuss the utilization of temporal databases for security, business event managers, knowledge discovery, and querying moving objects.

The paper **Applicability of Temporal Data Models to Query Multilevel Security Databases: A Case Study** by **Gadia** points out that the multiple value abstraction, required for temporal databases, is also useful for other domains, such as spatial databases and multiple beliefs, and that these are special cases of *parametric databases.* This concept is discussed, along with its applicability to multilevel security databases.

The paper **An Architecture and Construction of a Business Event Manager** by **Patankar** and **Segev** introduces the concept of a business event, and discusses types of temporal events, and event histories. The paper introduces an architecture and an SQL-like language to define these events.

Decision support and decision analysis systems serve as important motivation areas for temporal database applications. In the paper **Discovering Unexpected Patterns in Temporal Data Using Temporal Logic** by

Berger and **Tuzhilin**, the task of finding interesting patterns in temporal databases is discussed. The paper presents a categorization of different discovery tasks, and focuses on the task of discovering interesting patterns of events in temporal sequences.

The area of *spatio-temporal* databases is emerging as an independent area. The paper **Querying the Uncertain Position of Moving Objects** by **Sistla, Wolfson, Chamberlain,** and **Dao** proposes a data model for representing moving objects with uncertain positions in database systems. It also introduces a query language based on this model.

Part 4: General Reference: This part provides general information about the state of the art in temporal databases. It contains a **Temporal Database Bibliography Update** by **Wu, Jajodia,** and **Wang** that provides current references on models, database designs, query languages, constraints, time granularities, implementations, access methods, real-time databases, sequence databases, data mining, concurrency, and other papers. An up-to-date temporal database glossary prepared by **Jensen** and **Dyreson** and a glossary on time granularities by **Bettini, Wang, Snodgrass, Dyreson,** and **Evans** follows.

Appendix: Summaries of Current Work: At the conclusion of the seminar, all participants were invited to submit a brief summary of their activities in the temporal database area. These summaries, presented in the Appendix, provide a glimpse into some of the developments that we can expect to see in the coming years.

March 1998

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